

Numerical studies of the combustion of fuel oil in the boiler furnace at reduced load

Aleksandr A. Ivantsov, Andrey V. Gil^a

National Research Tomsk Polytechnic University, 634050 Tomsk, Russia

Abstract. Relevance of the work due to the need to assess the effectiveness and reliability of the boiler units on reserve fuel after reconstruction associated with a change in the base fuel and approaches of numerical analysis. Analysis of physical and chemical processes in the furnace volume of boiler BKZ-210-140 operating on reserve fuel and rated load when using the Euler and Euler combined and Lagrangian modeling approaches. Results of the numerical modeling of the processes of aerodynamics, heat exchange, and combustion in the furnace volume.

1. Introduction

The main conditions for the combustion of fuel oil to the boiler furnace are heating oil to the desired temperature, a thin and uniform atomization and good mixing with the oxidant. Since the combustion of fuel oil occurs in the vapor-gas state, the optimal organization of the combustion aerodynamics ensures the stability of combustion, and allows you to maintain the required speed and temperature in the furnace volume. Uneven and erratic movement of gases in the furnace, on the contrary, leads to the opposite result and can cause excess of allowable local heat loads, especially at low load operation of power boilers, so it is necessary to provide combustion processes depending on the scheme and the combustion conditions. Most effective for this use of numerical methods of three-dimensional modeling [1, 2].

2. Problem statement

The object of study is the boiler unit BKZ-210-140 – vertical tube, a single drum, natural circulation, with a dry ash. Nominal production of 210 t/h of superheated steam pressure of 14 MPa, the calculated temperature of superheated steam of 833 K. Furnace of the boiler volume of 1093 m³ is equipped with six low-emission gas-oil burners combined eddy thermal capacity of 30 MW each.

Burners are located in the side walls of the furnace in a triangle with the apex downwards (Figure 1). The air in the gas-oil burner is supplied from the air path after the air heater and spread to the central and peripheral channels through control valves.

As the estimated low-sulfur fuel received oil M100.

To suppress the formation of nitrogen oxides is provided a two-stage combustion system with tertiary air nozzles.

^a Corresponding author: andgil@tpu.ru

For combustion of fuel oil in the central part of the oil-gas burners installed steam mechanical injector type "Volcano". Before nozzles provided fuel pressure is not less than 0.2 MPa, pressure of at least 0.3 MPa, the temperature of the spray medium (superheated steam) of 473 ... 523 K, the specific steam consumption of not more than 0.02 kg/kg.

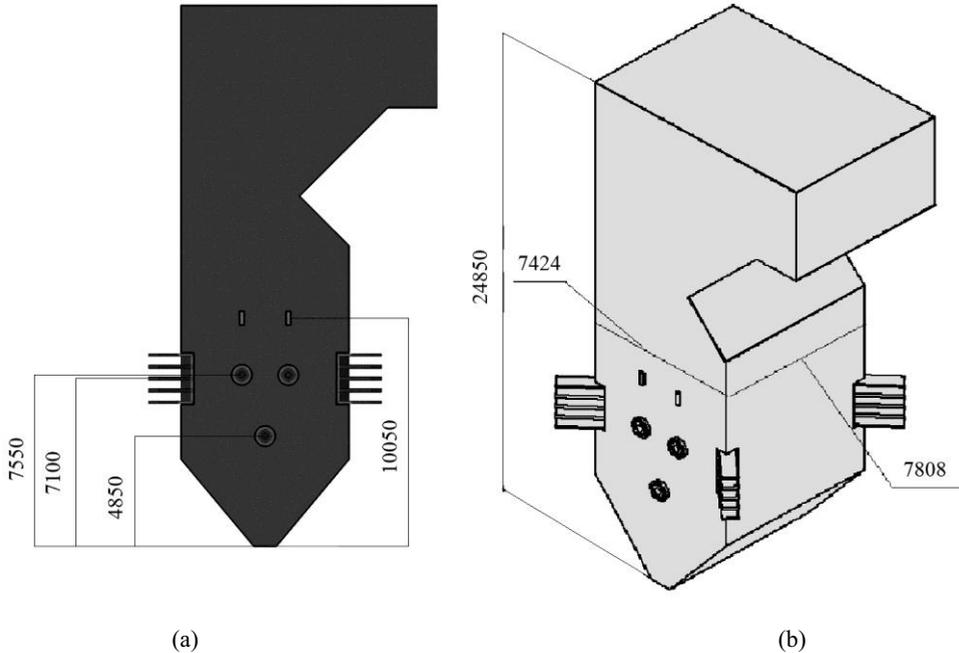


Figure 1. Sketch of the furnace (a) the lateral wall and (b) three-dimensional model of the boiler BKZ 210-140

3. Mathematical model

Numerical study of combustion processes carried out in the organization of liquid fuel combustion at 50 % load with the application package Ansys Fluent v. 12.1.4.

Boundary and initial conditions of the mathematical model is specified in accordance with the results of previously conducted thermal calculation of boiler BKZ-210-140 [3]. The initial data for the calculation assumed fuel - fuel oil ($C_{19}H_{30}$).

The numerical calculation is carried out based on the finite element method. Modeled physical and chemical processes: combustion of fuel oil vapors in air oxygen, turbulence in the reaction medium, convective and radiative heat transfer, and so on. Counting decided to simplify the process of oxidation of the fuel - the equation of gross oil vapor combustion reaction proceeds irreversibly in a single step: $C_{19}H_{30} + 26.5O_2 = 19CO_2 + 15H_2O$. Modeling of the gas phase was carried out in the approximation of Euler [4].

In accordance with the mathematical model comprises the equation (1) – (5):

- continuity

$$\frac{\partial(\rho U_i)}{\partial x_i} = 0; \quad (1)$$

- momentum

$$\frac{\partial \rho U_i U_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[\mu \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) - \frac{2}{3} \mu \frac{\partial U_k}{\partial x_k} \delta_{ij} \right] + \rho g_i, \quad (2)$$

$j = 1, 2, 3;$

- energy

$$\frac{\partial U_i \rho c_p T}{\partial x_j} = -\frac{\partial q_i}{\partial x_i} + \frac{\partial \tau_{ij} U_i}{\partial x_j} + S, \quad (3)$$

$$q_i = -\lambda \frac{\partial T}{\partial x_i}; \quad (4)$$

- state

$$\rho = \frac{p}{R_0 T \left[\frac{C_{O_2}}{M_{O_2}} + \frac{C_{N_2}}{M_{N_2}} + \frac{C_{C_{19}H_{30}}}{M_{C_{19}H_{30}}} + \frac{C_{CO_2}}{M_{CO_2}} + \frac{C_{H_2O}}{M_{H_2O}} \right]}. \quad (5)$$

Here x_i – are the Cartesian coordinates; U_i – are the gas velocity components; ρ is the density, p is the pressure; δ_{ij} are the Kronecker symbols; S are the turbulent Schmidt number; C_j are the concentrations of gaseous components; M_j – are the molecular weights of the gaseous mixture components.

To describe the characteristics of turbulent gas using a two-parameter «k-ε» turbulence model Launder and Spalding. The mathematical formulation of the radiative heat transfer is realized in the framework of P1-approximation of spherical harmonics method.

4. Results and discussion

Figure 2 shows the results of numerical simulations, which characterize the process of burning fuel as fairly stable, as in the area of active burning the absence of local high-temperature zones in the vicinity of the screen surfaces of the furnace (Figure 2). Temperature field with the values of 1773 – 1973 K mezhgorelochnom located in space at a distance of 0.3 – 0.4 m from the burner openings, which has a positive impact on the ignition and fuel burn up.

Heat flows are evenly distributed along the walls of the furnace, and an average of 150 kW/m² (Figure 2).

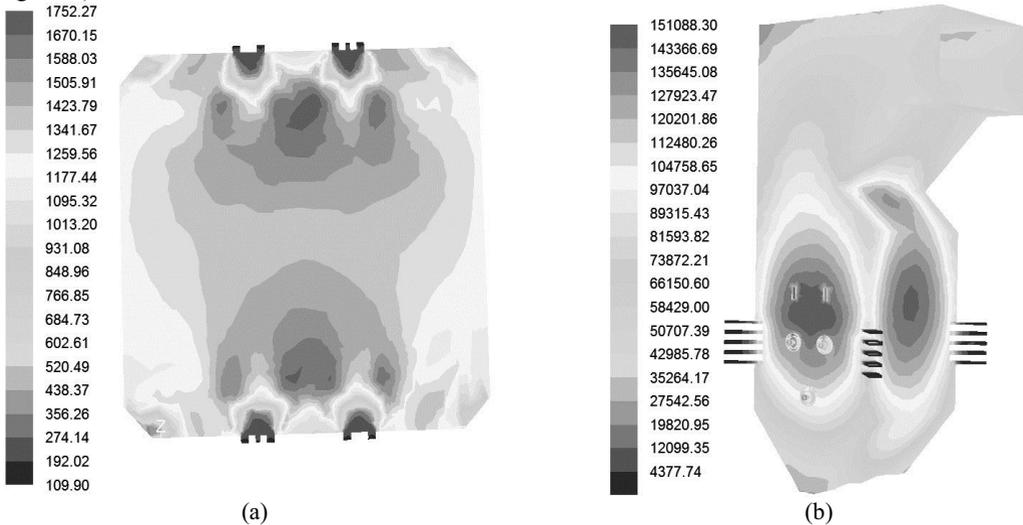


Figure 2. The results of the numerical visualization (a) the temperature field in the horizontal section along the axis of the upper tier grelochnyh devices (°C) (b) heat flux to the walls of the furnace (W/m²)

The curve shown in Figure 3, reflects the changes in temperature along the central axis of the furnace. In the lower part of the furnace, at the level of the middle of the ash hopper, the temperature is 1050 °C and further increasing the furnace height. At the level of burners temperature level reaches – 1400 °C, and the maximum value at the location of tertiary air nozzles – 1480 °C. Subsequently, the temperature level decreases reaching a value at the outlet of the furnace – 980 °C.

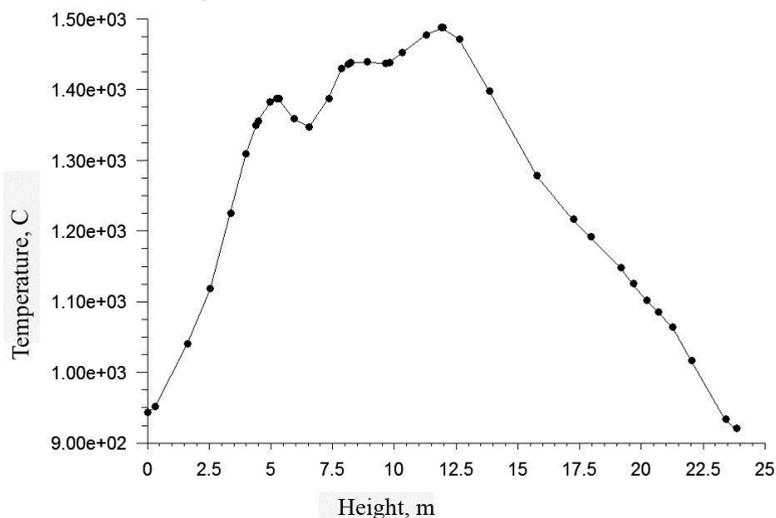


Figure 3. Changing the temperature adjustment of the furnace

5. Conclusions

Analyzing the results it can be noted that the institutions represented burning fuel oil by 50% load meets the requirements of the reliability of the evaporator heating surface and the efficiency of fuel burn.

Temperature level in the furnace volume uniform, which positively affects the reliability of the on-screen heating surfaces due to decreased heat hydraulic sweep circuits circulation.

At the exit of the burner units observed active mixing of fuel and air flow, which ensures complete fuel burn with the unburned carbon in the acceptable range.

Lack of high local zones and attacked the torch on the wall of the furnace allows operation of the boiler to ensure no negative factors caused by the high-temperature corrosion.

Despite the considerable tightening of staged combustion process fuel burnup is not observed due to increased suction air into the furnace that is reflected in an increased level of generation of nitrogen oxides.

The proposed approach is the numerical investigation of combustion processes allows the step of theoretical analysis to select the most rational option operation of the boiler unit.

References

1. A.V. Gil, A.V. Starchenko. *Thermophysics and Aeromechanics*, **19**, 503 (2012)
2. Gil A.V., Zavorin A.S., Starchenko A.V., Obukhov S.V. *Power Technology and Engineering*, **45**, 42 (2011)
3. *Thermal Computation of Boilers*. Normative Method, 3rd Edition, (NPO TsKTI, St. Petersburg, 1998)
4. A.M. Bubenchikov and A.V. Starchenko, *Numerical Models of the Dynamics and Combustion of Aerodisperse Mixtures in Channels*, (Tomsk State Univ., Tomsk, 1998)